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THE RELATIONSHIP OF SPEAKER INTELLIGIBILITY TO THE
SOUND PRESSURE LEVEL OF CONTINUOUS NOISE ENVIRON-
MENTS OF VARIOUS SPECTRA AND OCTAVE-BAND WIDTHS

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THE RELATIONSHIP OF SPEAKER INTELLIGIBILITY
TO THE SOUND PRESSURE LEVEL OF CONTINUOUS NOISE
ENVIRONMENTS OF VARIOUS SPECTRA AND OCTAVE-BAND WIDTHS

IDTHS

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18 March 1957

SUMMARY PAGE

THE PROBLEM

The effects of six tilted and six octave-band ambient noise spectra upon speaker intelligibility were studied as each spectrum was presented at six different sound pressure levels through 125 db. Constant level recordings were made of 48 speakers in the noises and these were subsequently played back to panels of listeners. The mean speaker intelligibility data were subjected to analyses of variance testing speech score differences attributable to spectra and sound pressure level.

FINDINGS

Generally, as the ambient noise surrounding talkers is increased in sound pressure level there is a decrement in speaker intelligibility whether the noise is of a tilted or an octave-band spectrum. The differences were highly significant statistically. The -3 db per octave tilted spectrum yielded an average decline in speaker scores of 2.3 percentage points per db between 105-125 db of noise. The most detrimental octave-band noise, 1200-2400 cps, averaged 0.75 percentage points lower scores per db.

Statistically significant differences were found among each of the two spectra types affecting speaker intelligibility. Greater differences were exhibited among the tilted spectra than among the octave-band noises.

INTRODUCTION

In keeping with the tasks specified by TED PEN AE 509049, the effects of noise of varying spectra and levels were studied as they were reflected by speech reception efficiency and by temporary hearing loss (9). The study demonstrated significant decrements in speech reception as the sound pressure level of the ambient masking noise increased; "shaped" or tilted spectra (a certain attenuation or boost per octave to a flat, white noise spectrum) were differentially masking to speech while the octave-band masking noises seldom yielded significantly different reception scores. The three shaped spectra most detrimental to speech reception showed a mean decrement of 3.7 percentage points per decibel increase of ambient sound pressure level above 110 db.

A further step would be to determine the effects of shaped spectra and octave-band ambient noise upon the speech efficiency of talkers. Changes in a speaker's vocal level have been reported as he attempts to compensate for the loudness of the environmental sound while maintaining satisfactory "self" signal-to-noise ratios (2,3). If the ambient noise levels do not greatly exceed the levels that talkers are able to achieve, theoretically the signal-to-noise ratios should remain relatively constant (4,6,8). The observed deviations from this "constant" ratio, and hence changes in speech efficiency, are due probably to those circumstances in which the speaker could not properly gauge the destruction effects of the noise or produce sufficient vocal output.

The present study was an attempt to find how ambient noise of six shaped (or tilted) spectra and of six octave-bands affect the intelligibility of speakers when each spectrum noise was presented at six sound pressure levels up to 125 db.

PROCEDURE

Four individuals (naval aviation cadets) served as speakers under each of the 12 noise spectra, hence, there were a total of 48 speakers. Each talker experienced the six sound pressure levels. There were two general types of ambient noise, all filtered from a "white" noise source: 1) six different shaped or tilted spectra, the slopes of which were characterized by a) a + 3 db per octave rise, b) a flat or 0 db slope, c) a - 3 db, d) -6 db, e) -12 db, and f) a -18 db per octave slope 2) six octave-bands of noise at a) 75-150 cps, b) 150-300 cps, c) 300-600 cps, d) 600-1200 cps, e) 1200-2400 cps, and f) 2400-4800 cps.

Each of the four speakers, talking in each noise spectrum condition, recorded six lists from either Form A or Form B of the Multiple-Choice Intelligibility tests (1,5). The speakers read on a six-second time interval beginning with the onset of one phrase and ending with the onset of the second word grouping, et cetera. The cue for reading was provided by an electronically timed flashing light. Each list was spoken concurrently with one of the six noise levels, i.e., "quiet" (42 db re 0.0002 dyne/cm²), 105 db, 110 db, 115 db, 120 db, and 125 db.

The voice signals of the speakers were picked up by a boom-mounted Altec 21-C condenser microphone positioned at the corner of the subject's mouth, out of the breath blast, and recorded on an Ampex 350 magnetic tape recorder. A relatively constant combined voice and ambient noise signal level was maintained within ± 5 db on the recording.

The ambient noise levels were introduced into the sound-treated recording room in a random order, produced by a 1000 watt noise generating system, the frequency response of which is essentially flat from 30 to 23,000 cps. This system was fed from an H. H. Scott Random Noise Generator, Model 811-A, and modified by either an SKL Variable Electronic Filter, Model 302, for the tilted spectra noise or a General Radio Octave-Band Noise Analyzer, Type 1550-A, for the octave-band noise. The six sound pressure levels were measured at the position of the speaker's head. Because the talker's microphone was of a broad-band frequency response type and was not of a "noise-cancelling" variety, the recordings were a composite of voice signal and the ambient noises.

In order that each speaker could monitor his own side-tone under higher noise level conditions than he could with a conventional HS-33 headset, each used a David Clark Co., 400-9D ear muff containing PHR-10 earphones. A single level was set in the speaker's side-tone circuit and was not changed from speaker to speaker or during increases in the ambient noise levels. This condition resulted in minimal side-tone for most speakers at 120 db noise level and probably none at the 125 db level, especially when the energies were concentrated in the lower frequency ranges.

To make possible the widest frequency response upon playback, the recordings were made so that there was a 2 db per octave attenuation below 800 cps to compensate for playback equalization. The equalizing network was also set to attenuate 10 db at 10,000 cps minimizing the reflection effect peaked at 8000 cps due to the boom-mounted microphone position.

The recording of each speaker was played to two panels of listeners, 10-14 per panel, resulting in a mean speaker score composed of 20-28 listener responses. The recordings were played back through an Ampex, Model 350, magnetic tape recorder with the signals amplified by an Altec 250A control console. This system fed a headset circuit of matched PDR-8 earphones mounted in NAF-48490-1 doughnut earphone cushions. The listeners were in a soundproofed room in which an 85 db sound pressure level (re 0.0002 dyne/cm²) of ambient ASA white noise was maintained, and they received the composite signal-noise recordings at a mean sound pressure level of 94 db under the earphone cushions.

RESULTS

The criterion measures for analysis were the mean speaker intelligibility scores under each noise spectrum at each sound pressure level of ambient noise. The results

for tilted or shaped spectra types and for octave-band spectra are reported separately.

TILTED SPECTRA

The criterion measures were treated by an analysis of variance technique termed by Lindquist as Type I (Mixed Design) (7). A summary of the analysis is found in Table I.

Table I

Summary of an Analysis of Variance Testing Differences
Among the Effects of Various Shaped Noise Spectra and the
Ambient Sound Pressure Level of the Noise upon Speaker Intelligibility

Source of Variance	df	Sum of Squares	Variance	F
Between subjects	23	14,024.68	609.77	
B (spectra)	5	14,643.41	2928.68	101.620*
error (b)	18	518.83	28.82	
Within subjects	120	31,667.62	263.90	
A (levels)	5	16,937.47	3387.53	30.538**
A x B	25	4,746.16	189.85	1.711
error (a)	90	9,983.99	110.93	
Total	143	45,692.30		

* $F = ms_B / ms_{error(b)}$; significant at the 1 per cent level of confidence, 5 and 18 df

** $F = ms_A / ms_{error(w)}$; significant at the 1 per cent level of confidence, 5 and 90 df

The F ratios for levels (30.54) and for spectra (101.62) show differences among each significant beyond the 1 per cent level of confidence. The interaction F ratio between spectra and level of 1.71 was non-significant. An examination of means, shown in Table II, indicates a general decrement of intelligibility scores as the ambient noise level was increased. Figure 1 is a graph of the mean speaker intelligibility scores plotted against sound pressure level with each spectrum as a parameter.

A reversal of the general trend of lower intelligibility scores with increased level occurred between the 110 db and 115 db ambient noise level for all spectra except the -3 db and -6 db/octave noises. The general trend was minimal. However, for the -18 db/octave spectrum there was no trend, and the 115 db noise level scores were higher than during the quiet condition.

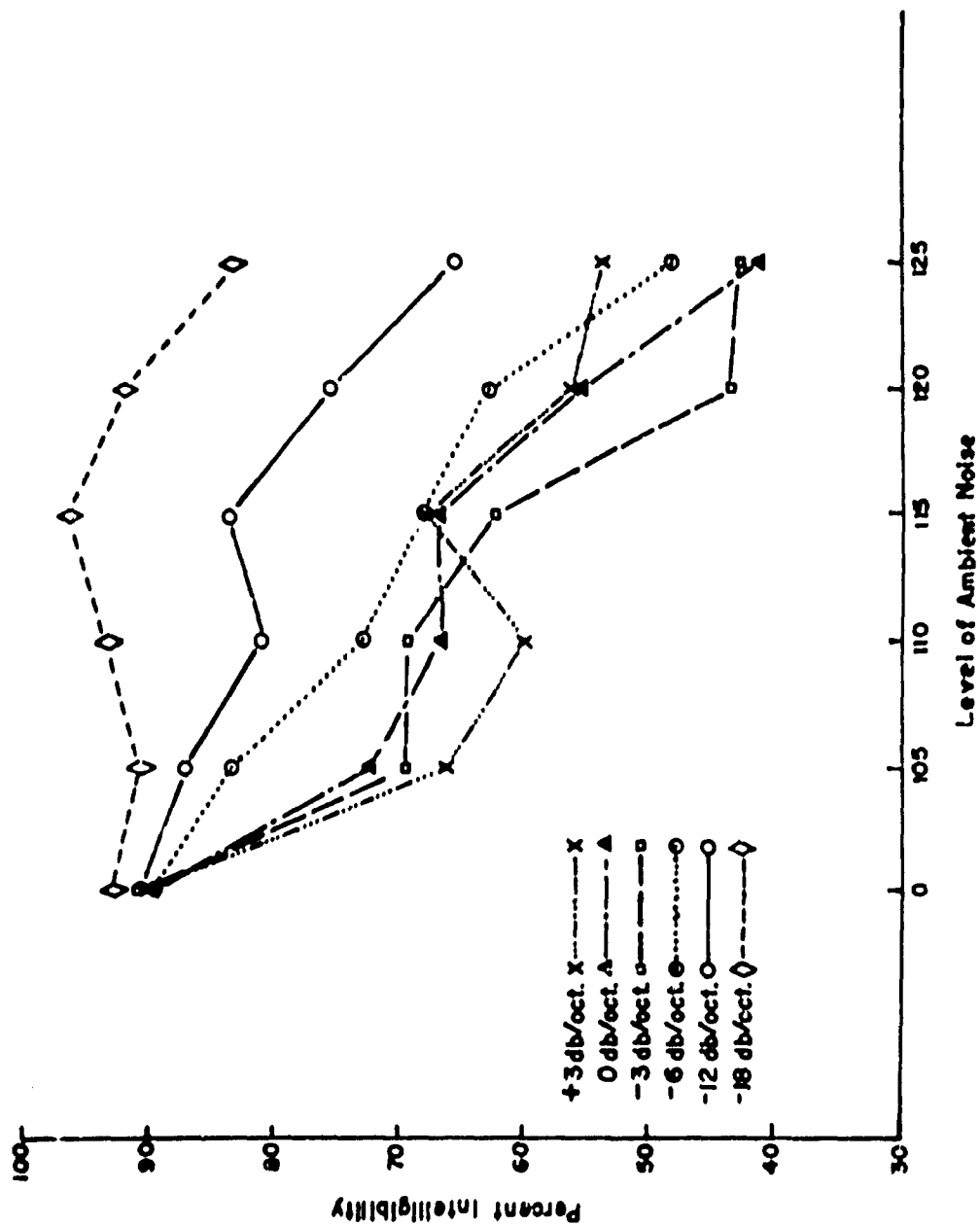


FIGURE 1

SPEAKER INTELLIGIBILITY SCORES AT EACH AMBIENT NOISE LEVEL WITH THE SHAPE OR TILT OF THE FILTERED NOISE SPECTRUM AS THE PARAMETER OF EACH CURVE

Table II
Means of Per Cent Speaker Intelligibility Scores Resulting from
Ambient Noise Environment of Tilted Spectra Variety

Slope/db/octave	Sound Pressure Level						Means
	Quiet	105 db	110 db	115 db	120 db	125 db	
+3	90.6	66.2	59.9	67.8	56.1	53.7	65.7
0 (flat)	89.6	72.0	66.5	66.7	55.3	41.4	65.3
-3	90.6	69.3	69.1	62.4	43.7	42.8	62.9
-6	89.6	83.3	72.9	67.7	62.9	48.2	70.8
-12	90.5	87.0	81.0	83.7	75.5	65.4	80.5
-18	92.7	90.7	93.1	96.3	92.0	83.1	91.3
Means	90.6	78.1	73.7	74.1	64.3	55.7	

The relative effectiveness of the six tilted noise spectra to mask or interfere with speech intelligibility can be abstracted generally from the extreme right hand column in Table II. The function of per cent intelligibility scores on the ordinate against spectra along the abscissa is shown in Figure 2. Sound pressure level is the parameter. The masking or interference of speech under the present experimental conditions could be ranked as regards spectrum: a) -3 db per octave, the most destructive, averaging 2.3 percentage points decrement per db between 105-125 db noise levels, then b) flat or 0 db per octave slope, c) +3 db per octave, d) -6 db per octave, e) -12 db per octave, and f) least destructive, -18 db per octave.

The data indicate that both spectra and sound pressure level changes affect the intelligibility of speakers who talk in an ambient noise field of the tilted noise variety.

OCTAVE-BAND SPECTRA

The mean speech intelligibility measures obtained from the octave-band noise conditions were treated by the same Type I analysis as the tilted spectra data. The analysis is summarized in Table III.

F ratios for both level and spectra were significant. The F for differences attributable to sound pressure was 16.87, with 5 and 90 df, significant beyond the 1 per cent level of confidence. The F ratio for differences among spectra was 3.69 with 5 and 18 df, significant at the 5 per cent level of confidence. The ratio for interaction between levels and spectra was also significant at the 5 per cent level of confidence, 2.16, with 25 and 90 df.

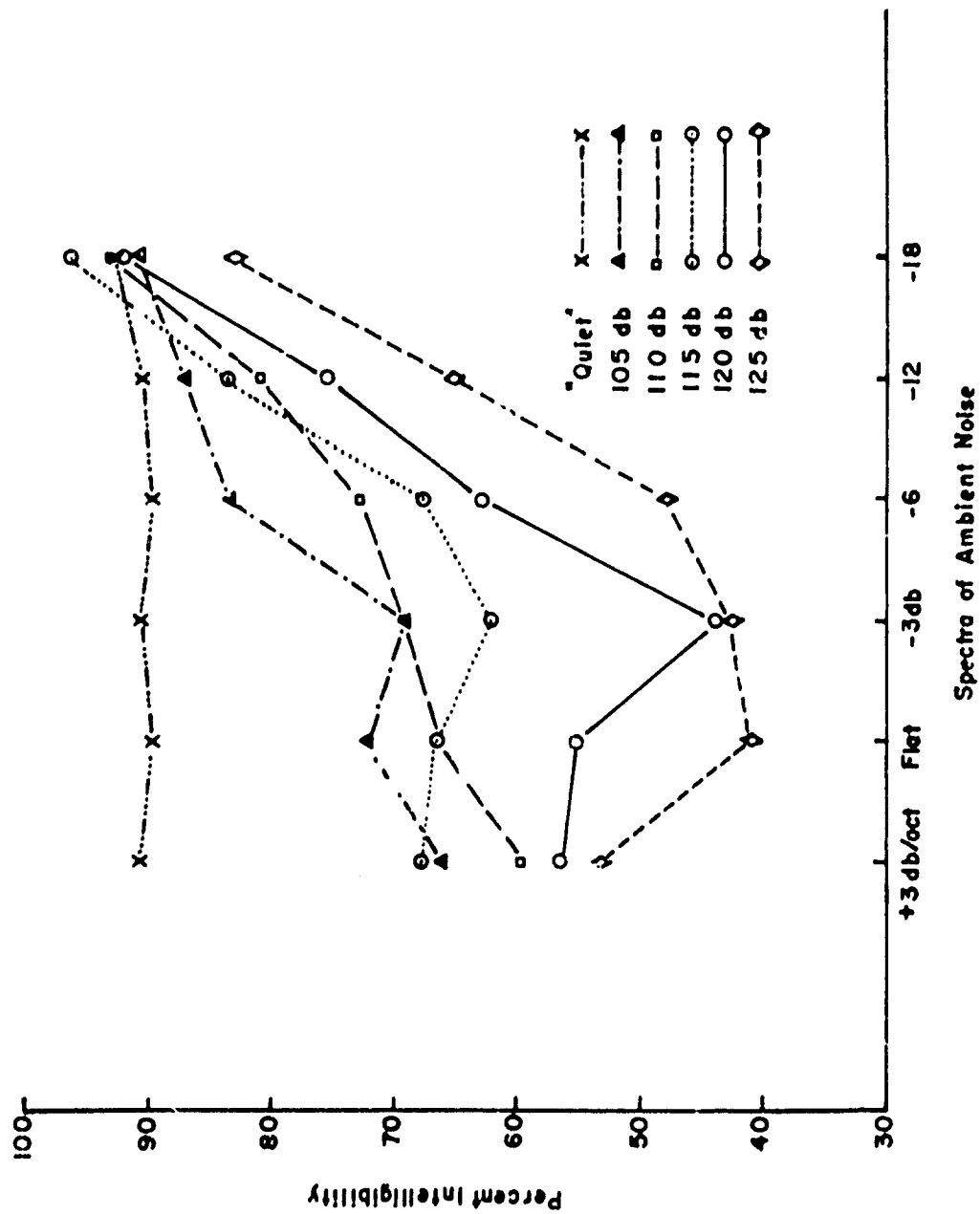


FIGURE 2

SPEAKER INTELLIGIBILITY FOR EACH SPECTRUM OF TILTED NOISE WITH
SOUND PRESSURE LEVEL OF THE NOISE AS THE PARAMETER OF EACH CURVE.

Table III

Summary of an Analysis of Variance Testing Differences
Between the Effects of Various Octave-Band Noise Spectra and the
Ambient Sound Pressure Level of the Noise upon Speaker Intelligibility

Source of Variance	df	Sum of Squares	Variance	F
Between subjects	23	5,763.72	250.59	
B (spectra)	5	2,918.76	583.75	3.69*
error (b)	18	2,844.96	158.05	
Within subjects	120	6,778.12	56.48	
A (levels)	5	2,504.86	500.94	16.87**
A x B	25	1,601.09	64.04	2.16
error (w)	90	2,672.35		
Total	143	12,541.84		

* $F = ms_B / ms_{\text{error (b)}}$; significant at the 5 per cent level of confidence, 5 and 18 df

** $F = ms_A / ms_{\text{error (w)}}$; significant at the 1 per cent level of confidence, 5 and 90 df

The mean speaker intelligibility scores are given in Table IV. In general, they indicate for most of the octave-band noises a deterioration of scores with increased sound pressure levels. For most spectra, however, changes were minimal or slightly increased between 110 and 115 db; see Figure 3.

Table IV

Mean Speaker Intelligibility Scores When the
Ambient Noise Environment Was of the Octave-Band Variety

Octave Bands	Quiet	105 db	Sound Pressure Level				Means
			110 db	115 db	120 db	125 db	
75-150 cps	92.6	94.4	91.5	93.2	92.7	92.1	92.7
150-300	89.6	89.8	88.7	88.5	82.3	80.8	86.5
300-600	91.6	82.4	86.5	87.7	85.9	74.9	84.6
600-1200	93.9	83.5	81.5	70.8	78.3	78.8	82.5
1200-2400	93.7	78.9	80.3	80.1	71.0	64.9	78.2
2400-4800	90.6	92.6	91.1	87.2	85.0	80.0	87.6
Means	91.9	86.9	86.5	85.9	82.5	78.4	

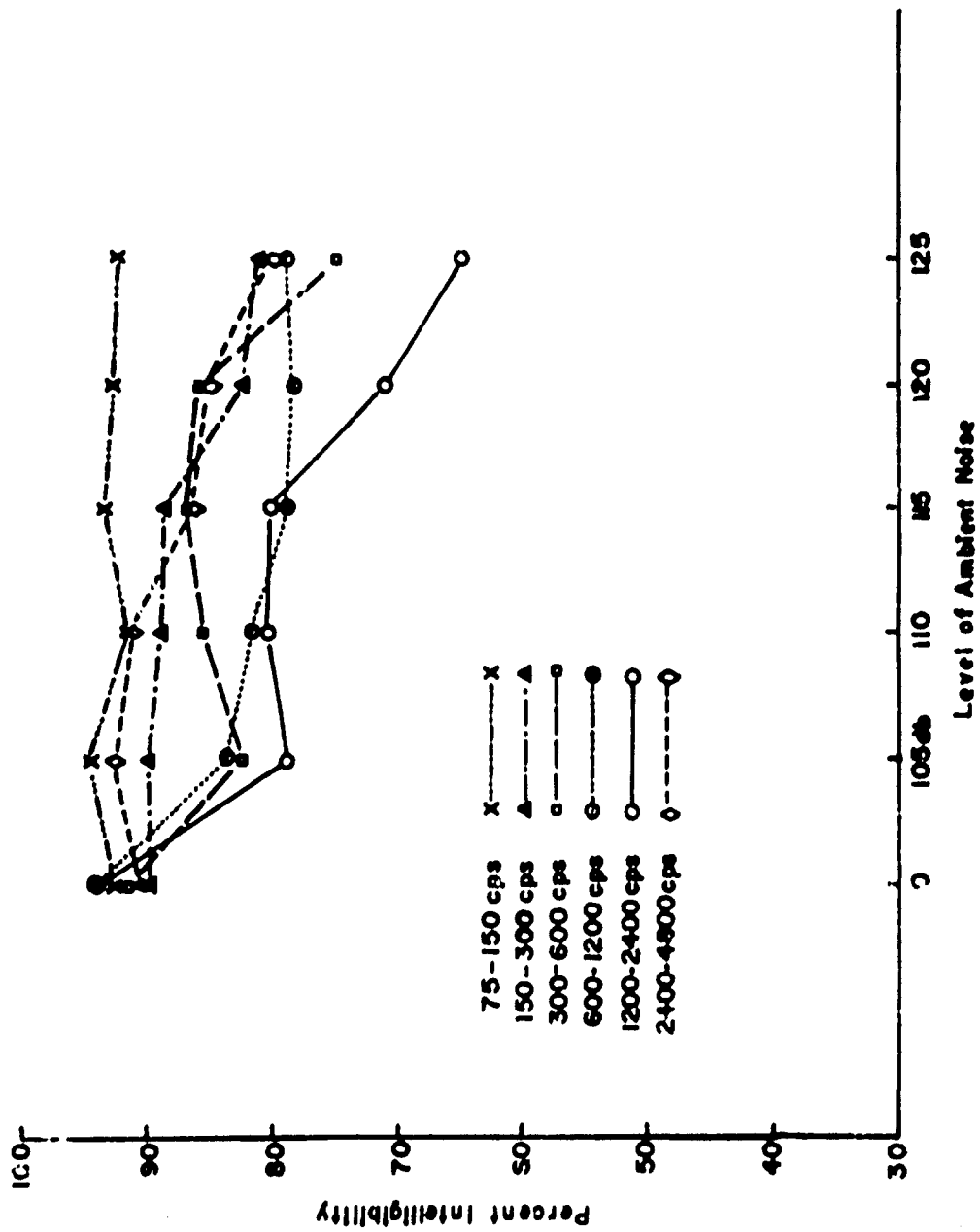


FIGURE 3

SPEAKER INTELLIGIBILITY SCORES AT EACH AMBIENT NOISE LEVEL WITH THE OCTAVE BANDS OF THE FILTERED NOISE AS THE PARAMETER OF EACH CURVE.

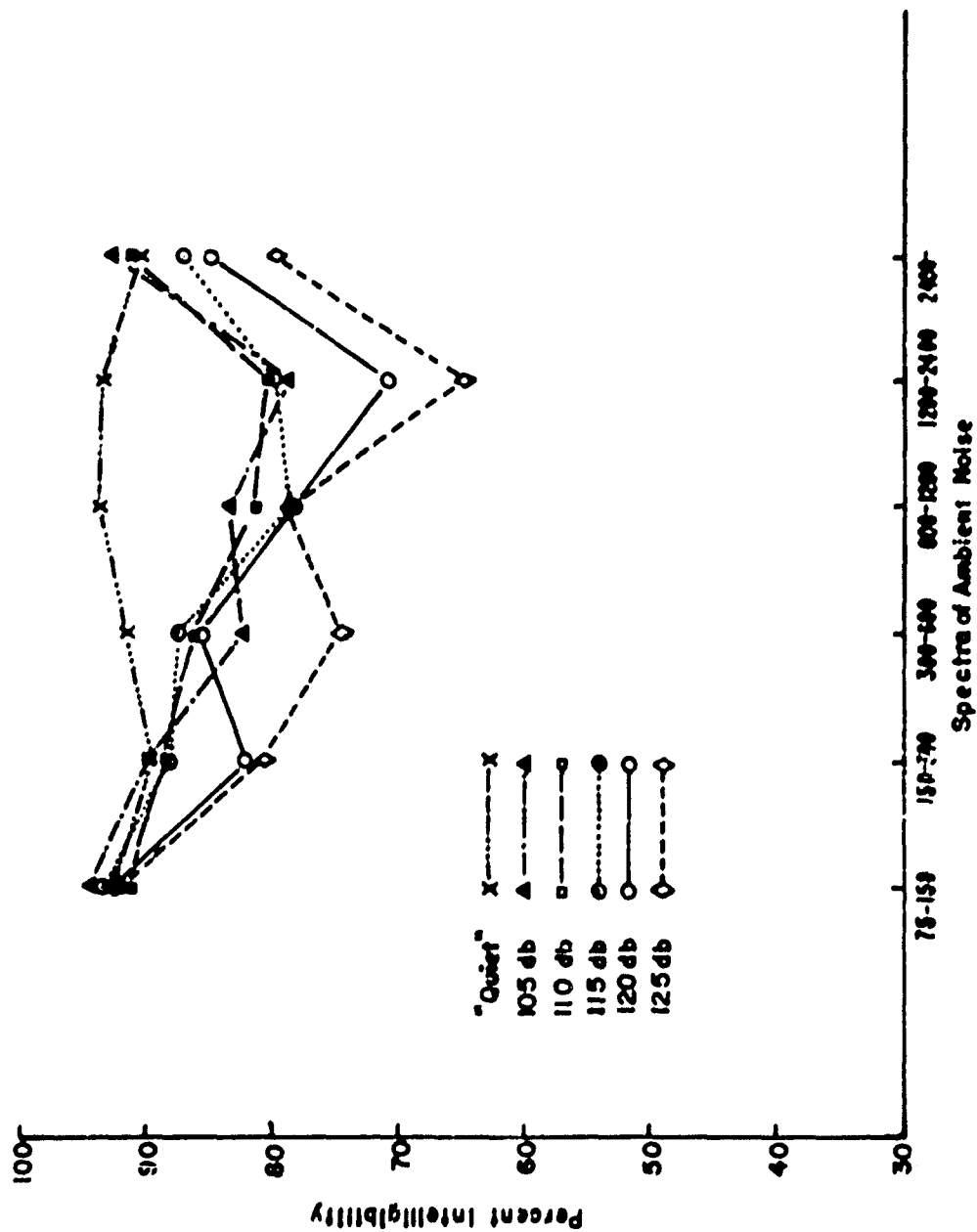


FIGURE 4

SPEAKER INTELLIGIBILITY FOR EACH OCTAVE BAND OF NOISE WITH THE
SOUND PRESSURE LEVEL OF THE NOISE AS THE PARAMETER OF EACH CURVE.

The relative effectiveness of the octave-bands of noise in masking a speaker's intelligibility could be ranked from most destructive to least destructive as follows: a) 1200-2400 cps, b) 600-1200 cps, c) 300-600 cps, d) 150-300 cps, e) 2400-4800 cps, and f) the 75-150 cps band. Figure 4 is a plot of speaker intelligibility scores on the ordinate and octave-bands on the abscissa with sound pressure level as the parameter. The differences between adjacent bands are not large except between the 75-150 cps and 150-300 cps, and then on the upper end between 1200-2400 cps and 2400-4800 cps. Generally, the differences between 1200-2400 cps band and the two adjacent bands are greater than for any of the others.

The analysis of the data for this portion of the study indicates highly significant differences resulting from ambient octave-band noise sound pressure levels upon speaker intelligibility. Significant differences were found for both spectra and interaction effects.

DISCUSSION

There is a high degree of similarity between the speaker intelligibility score differences of the present study and the speech reception score differences of the previously cited earlier study when the values resulting from the tilted spectra and the octave-band spectra as a function of sound pressure level are considered. The two studies are not directly comparable since the experimental design and analysis of the two, although similar, were different. Changes in tilted spectra result in a highly significant F ratio for speaker intelligibility and consistently significant F ratios for speech reception. From the results of the -6db per octave sloped spectrum it is possible to abstract an average decrement of scores as the sound pressure level increases. For speaker intelligibility the scores declined 1.75 percentage points per db between 105 and 125 db, while the reception scores (taken from the earlier study) were attenuated 2.0 percentage points per db between 100 and 130 db. Essentially, the earlier reception and the present intelligibility studies compare signal-to-noise relationships. In the reception study the signal-to-noise ratios remained constant for the listener under a given noise condition, while in the present study the speaker's vocal level was not restricted except by his own side-tone level and the maximum effort that he could muster and maintain at the higher ambient noise levels. The observed differences, then, become ones for which the speaker could not properly gauge the destruction effects of the ambient noise and/or ones for which he was unable to compensate.

OCTAVE-BAND SPECTRA

The effects of octave-band noise upon speaker intelligibility yielded a significant F ratio (5 per cent level) among spectra. This ratio probably is attributable in a large measure to the 1200-2400 cps and the 600-1200 cps band. The significant F for spectra also may be accounted for in the significant interaction ratio, but from an examination of Figure 3 it would seem that the interaction effects could reduce the highly significant

differences attributable to level to non-significance, especially in the noise bands of 600-1200 cps and 1200-2400 cps.

The speech reception scores, however, showed no significant differences for spectra below the 115 db level (Y). Differences due to sound pressure level changes were significant in all octave-bands during the initial part of noise exposure, but the scores either developed plateaus or "bounced" as time-in-noise progressed.

In the present study the most destructive octave-band noise attenuating speaker intelligibility (1200-2400 cps) yielded an average, a questionable procedure for this curve, of only 0.75 percentage points per db decrement due to increased noise level. It is interesting to speculate whether or not one explanation for the difference in speaker scores for this band could be that it contains the second formant frequency region, which supposedly contributes most to speech sound discrimination. This may account for the reduction in intelligibility scores of some 15 per cent under a 20 db noise increase. The octave-bands used in the present study may be close enough to the Equal Articulation Bands that discrimination remains relatively unaffected. However, the masking by octave-bands could be likened to a "probe masking" technique now under exploration. The data from this method indicate that the band 1100-1500 cps is the most destructive under decreased signal-to-noise conditions. This particular region partially overlaps the 1200-2400 cps band of the present study.

TILTED SPECTRA

The decrement of speaker scores under tilted spectra conditions does not appear to be as systematic as were the comparable reception scores from the earlier study. Perhaps the factor contributing most to non-linearity was the speaker adjustment in vocal output as the level of ambient noise increased, tending to mask side-tone.

One other factor aiding non-linearity and presumably related to the speaker vocal-level adjustment was that in the recording process the over-all combined speech signal and noise was held to a common level which for some speakers could result in an increased signal-to-noise ratio to the listeners. It was observed that during the speaker recording process the step between 110 and 115 db seemed to be the one in which the ambient masking noise was returned to the speaker's headset at such a level that the result was a sharp increase in speech level. When the composite signal and noise was adjusted to the common recording level, the result was an elevation of speaker scores at the 115 db level for most tilted spectra (Figure 1). The -6 db per octave sloped noise, incidentally the one most resembling jet aircraft noise, approached linearity, averaging 1.8 percentage score points per db. The other spectra, except the -3 db per octave, show a "hump" at the 115 db ambient noise level.

GENERAL

The relative horizontal linearity of the quiet condition seems to indicate that the multiple-choice intelligibility test lists were not contributing statistically to differences found under the various noise conditions or that speakers who could be classified as highly intelligible were not stratified in the recording process.

As the experimenters listened to the recorded stimulus tapes and when individual speaker's scores were examined, certain of the speakers seemed to be able to achieve some vocal condition while speaking in noise which made that individual's speech more intelligible than that of his fellows. An extension of the present study is underway using the combined speech and noise recordings to arrive at some common factors which may be abstracted from: a) an analysis of the tapes for signal-to-noise ratios of voices yielding either high or low intelligibility scores, voice fundamental, syllable duration, and perhaps average peak power; and b) judgments of precision of articulation and presence of certain voice qualities (harsh, pleasing, breathy, high or low pitch, et cetera). Some of the physical measures and/or judgmental factors may yield hints as to the qualities that make for good or poor speakers when they must communicate in a noisy environment.

CONCLUSIONS

1. Increases in the sound pressure level (quiet to 125 db) of the ambient noise of various tilted spectra surrounding speakers are detrimental to intelligibility scores at a statistically significant ratio, and can be ranked as to their detrimental effects upon speaker intelligibility, i.e., -3 db, 0 db, +3 db, -6 db, -12 db per octave sloped noise, but not for the -18 db per octave noise at levels below 120 db. These decrements averaged 2.3 percentage points per db increase for the -3 db per octave noise and 1.8 percentage points per db increase for the -6 db per octave noise.
2. Statistically significant differences were found among tilted noise spectra as to their influence upon intelligibility.
3. As the sound pressure level of ambient octave-band noise surrounding a speaker is increased, the intelligibility scores are reduced significantly. The noise band most detrimental to intelligibility was the 1200-2400 cps band.
4. Differences among octave-band spectra were found to be statistically significant as to their effect upon speaker intelligibility.

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